Opportunities offered by Space Technology to Enable the Next Giant Leap in the Evolution of Humanity

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Abstract

As humanity entering the new millennium with many of the profound challenges ever encountered in the history of mankind due to population increases faster than wealth creation, surge of ambitions by many countries to achieve better life independent of risk or their available resources and capabilities. The challenge to predict or control the evolution of world crisis is even harder because of the ease in acquiring knowledge, information, and technical capabilities by any individual or group due to the wide spread of "know-how" through the internet to all people without having to invest in technology development. The three most critical issues confronting humanity today and perhaps for the next few thousand years ahead are: (1) Energy and Life/Health Sustainability, (2) Human Adaptability and Survival within the need and ambitions of others and, (3) Guided Human Creativity to satisfy more material needs with less resources, and Balance of Global Geopolitical Power Systems, among others. Related to these issues is the current global ecological crisis caused largely by the "petrochemical civilization" of mankind, as the world economy since the industrial revolution, has been built upon a none-sustainable energy resource. Given the energy technology status today and the fact of greenhouse gases from fossil fuel consumptions, mankind is consuming too much (energy, food and water) and their developments have severely diminished natural ecosystems of this planet. The Earth system's biogeochemical cycling of energy and nutrients has been ripped apart and subsequently the global ecological system, which provides humans, their habitat is failing. Therefore, the ultimate solution lies in the sustainability of energy resources, which reverses the harm to the earth environment. The most viable, logical and ultimate energy resource (among many other renewable energy forms) for mankind for thousands and millions of years ahead is naturally from harnessing the unparalleled power of our solar system - the SUN, not only for energy, but for enhancing food productions, weakening hurricanes, acquiring through lower cost transportations new and improved materials from other planetary objects, and hopefully in the future enable "Life beyond Earth". Any shift from the present suite of large-scale infrastructure-intensive technologies to another will be unlikely to achieve the next giant leap of humanity within a foreseeable future, unless a collaborative human endeavor such as the "Space Program" like project on solar energy R&Ds (both land and space-based) is to be embarked by the collective wisdoms of the entire global society. The key to successful transition from one technology infrastructure to another is three progressive evolutionary stages. First, the technologies to be reshaped or developed must have markets that are nearer term and multi-faceted to retire risk and build financial confidence. Second, interim reasonable cost to value products must be created to become credible to both businesses and government to validate profitability. And, finally integrated subscale interim systems must be possible that are affordable to generate the capital for the next stage, which responds to the next bigger market. This paper will explore these questions, focusing on potential promising technologies, markets, and opportunities.

Keywords: Power from the Sun, Wireless Power Transmission, frequency allocations.

1. Introduction

Beginning in the early 1960's, the concept of transporting microwave power from one point to another via free space propagation gained interest. The earliest concept was a periodic array of lenses or reflectors that maintained beam integrity and circumvented the usual inverse square law for free space propagation. This arrangement has come to be known as a "beam waveguide" and is capable of nearly 100% efficient transfer of the microwave power. (Goubau and Schwering 1968)(Christian and Goubau 1961) At the same time, it was conjectured that such microwave power transfer, termed "power beaming," could be applied to power aerial vehicles or to transfer power to the ground from a geosynchronous satellite on which the microwave power is generated via large arrays of photovoltaic cells. (Glaser 1992)(Brown 1992)(Koert and Cha1992). Over the years, much theoretical work was carried out concerning the proper aperture distribution to use at various ranges. (See for example (Kay 1960)(Letaw, Hamm and Slocum 1961)(Hansen 1985)(Hansen, Mc Spadden and Benford 2005). Two key demonstrations stand out as milestones in the development of this concept. Brown (1992) demonstrated the powering of a helicopter by microwaves and Dickenson (1976) demonstrated the beaming of 34 kW over a range of 1.54 km. More recently, the Canadian Department of Communications proposed a system for microwave powered aircraft and studied many of the issues involved in its implementation. (East 1992) Still more recently, the Japanese built practical hardware for beaming large amounts of power with a plan for scaling to the 10 GW level. (Iizuka et al. 2004) Much of this work is predicated on the use of high power microwave tubes such a magnetrons or gyrotrons to convert the power to rf (Woo et al. 1989)(Benford et al. 1989)(Levine et al. 1991). However, high power microwave tubes present difficulties arising from the high power density and the need to distribute the power to a number of radiating elements.(Scharfman, Taylor and Morita 1964) The system proposed here, on the other hand, uses low power solid state devices to convert the dc to rf, resulting in a lower power density everywhere in the system. This approach eliminates the problems associated with breakdown of the air and other materials, power handling capacity of the components, high concentrations of thermal energy, and health and safety issues. An alternative has been proposed recently in which solar radiation is directed at the intended receiver via an optical train and then converted to dc by a thermal engine eliminating the rf link altogether. (Turner 2006) This scheme is, however, in its infancy and it remains to be seen how effectively the optical radiation can be generated, directed, and converted as needed. Microwaves can be used to efficiently and safely transport power to a remote location where it can be converted to dc (or ac) power by a "rectenna." (McSpadden et al. 1998). The proposed system is based on spatial power combining (Mink 1986)(Navarro and Chang 1996) of the outputs of a large number of devices synchronized by mutual injection locking.

2. Energy and Sustainability: The Concept of Space Solar Power: Harnessing the SUN

The energy sustainability determines virtually every aspect of the challenges for sustained human development. Much like our ancestors had learned the use of "fire" which leapfrogged human civilization into the stages of cooking and tool-making, harnessing the energy of the SUN will not only reducing or diminishing many of our crisis, but it most certainly is going to bring about the next giant leap in the evolution of humanity.

As it becomes ever evident, based on a most recent discovery by NASA, that there has been nearly 10% per decade decrease of ice cover in the Antarctic, and a 31% melt increase in the Greenland ice from 1979 to 2005 time period. Regardless of natural or human causes, the global climate is changing at an alarming rate. The Vikings disappeared from the Greenland during the medieval age, some 15 thousand years ago because they did not adapt to a few degrees of temperature change. While determined to reduce or eliminating CO_2 emissions, humans must adopt ourselves to the inevitable change of nature conditions under which we must survive. This of course, including expanded human explorations in the space, science and technology frontiers for outer space settlement within this millennium, in order to prepare mankind to adopt and survive in other destinations of the solar system should planetary disasters strike on humanity. Human adaptability must not be used as an excuse for our own destruction of the natural harmony, and our plunder of the earth's resources. This is why we must recognize the importance of ecological balance and the interdependences of all lives on earth. It is not just an issue of avoiding global ecological collapse, the death of billions; it's an issue of end of human civilization and the survival of humanity.

3. Guided Human Creativity and the Balance of Power

Science and Technological civilization of humanity has reached a pivotal point of overwhelming creativity and productivity, and this has brought mankind not only rapid economic expansions, globalization and complex societal interdependencies, it also unleashes the unpredictable (oftentimes uncontrollable) technological forces, which are of extremely capable in both sides of the destructive and constructive human ventures. Such risks and susceptibility of planetary ruins or total extinction of humanity via self-destructive human confrontations is continuing to grow. Poverty, war, technology and disparity of resources distribution have led to the serious imbalance of the geopolitical power sharing around the globe, which in turn fueled the hatred and conflict between human civilizations and between the haves and have-nots, and consequently gave birth to modern terrorism. The cycling of destructive forces are self-compounding, and are driving the rich richer, the poor poorer and the powerful more dangerous, thus emboldened to wage wars or use of more violent means to resolve confrontations within fellow mankind. All in all, the inability of mankind to guide its won creativities, therefore to managing or balancing the global economic and military power has been largely responsible for the moral political crisis exist today. And if such a profoundly critical issue is not resolved in the nearest possible future, there are calculable risks that the abuse of power, abuse of science and technology creations will sooner or later bring about the eventual ruins of our planet, and ultimately our total extinction as human species.

Now, let us address the issue of energy sustainability – basically whether humans should "heads up" to explore energy from space; from the Sun – the source of everything within our solar system, or we should still "heads down" and keep looking beneath the surface of this planet for answers of our future energy supply? As an outline, I will talk about humanity at the crossroads: the quest for energy and sustainability; setting priorities and choosing wisely: defining criteria and requirements for energy choices; time to harness the Sun – this will be my major focus, because it is utterly important and I see it as the next giant leap for mankind; and finally solar energy from space: a "Manhattan Project" for humanity.

4. Humanity at the Crossroads

From a risk-assessment perspective, I see the energy issue as basically a risk-based decision-making issue. Whether or not we choose each option of energy alternatives, it's basically decision-making for sound energy policies for the future of mankind in an ever increasingly complex global environment. Therefore, it's not quite a deterministic thinking process; there need to be a probabilistic-based thought process as well. From the angle of energy risks, I see energy shortage as the roots of all risks facing mankind. In other words, energy is the root cause of all crises confronting humanity. Economic imbalances, for example – all the consequences we see today: ecosystem and environmental crisis; poverty, diseases, and lack of water and food; war and global/regional confrontations; terrorism; increased natural disasters; corruption and political tyranny; more arms-race and destructive technology; un-peaceful or unguided human creativities; social, cultural, and moral crises. All together, it comes to a negative cycling of human evolution. The worst-case scenario is that wrong energy source for the planet leads to human extinction. Basically, it's a self-destructive and self-compounding risk scenario leading to possible human extinction.

Everything is closely connected and interdependent. The risk initiator is the wrong sources for human energy consumptions. If you have the wrong sources, you have reoccurrence of various crises; you have a war-driven economy; and you have misguided science/technology creativity. You have environmental disasters; you have a dying ecosystem; you have nature disasters. As long as there exist an imbalanced world economy, there is room and nutrient for terrorism. All together, you have a miserable social, economical and natural world environment, thus an unlivable planet. You can see that global warming is a pretty serious problem. In my view, it's the Number 1 risk of a Combustion World Economy. So, you see that there is a very good correlation of a global temperature increase with the concentration of the CO_2 level. You can see the 1979 Arctic Sea ice range and see clearly how fast it has shrunk in the last couple of decades. The consequence I see of a catastrophic climate change is that it will lead to irreversible ecosystem dying out, so as our species.

5. Braking the vicious cycle of greater appetite for Energy

Mankind must break the violent and destructive nature of a nonsustainable combustion economy. That is my viewpoint. The nature of a combustion world economy is evidently this: The more demand for oil exceeds production of oil, the higher the price goes. The higher the price goes, the more dislocations the world economy suffers. The more dislocations the world economy suffers the more resource wars the human population endures.

Humanity's quest for energy: from the primitive use of fire to the use of randomly discovered fossil fuels to the intelligent and creative use of sustainable energy sources. We need to embark on humanity's third giant leap. The first giant leap was when human beings got down from the trees and started to use fire. Then we discovered electricity, and electricity brought modern industrialization. Now we're running into profound energy crisis. Mankind must now initiate the next giant leap of our civilization, which is to Harness the Sun and therefore transforming the combustion world economy into the Solar-electric world economy!

To go quickly over the history of energy technology, there were four eras of energy in human history. Not even a thousand years ago, our lives were based on wood-generated energy, basically firewood. Starting about 1600, we found coal. About 1800 we incidentally discovered oil and gas. The relative prices of energy went down sharply, and now it's going to go up sharply very soon. As we can see from year 2000 on there is great uncertainty for the world energy supply, whether or not we engage in sustainable energy R&D, it's up to us. The fossil fuel age on the scale of human history – as Bob Citron showed us in the movie this morning – if you plot the energy demand by year of human civilization on a terawatt scale, you will see a huge bump barely a hundred years ago. Before that, in the Stone Age, basically the cultivation of fire was the early human primitive creativity that led to the emergence of agriculture, cooking, tool-making, and all the early stages of human civilization. After about 150 years of burning fossil fuels, the Earth's 3 billion years' store of solar energy has been plundered.

There is now an energy crossroad before mankind. My thought is that we have, basically, two ways to go. Either we do energy based on cosmic-based, open, and unlimited original resources, which means everything comes from the stars, or we do Earth-based, local and confined secondary resources. As we all know that every single bit of energy comes from the Sun. We humans have a small window of opportunity that exists, in my view, from 2000 on for maybe the next couple of decades. Either we're going to go down or we're going to go up and continue to survive as a species. We must set priorities and choose wisely. The projected world energy use by fuel type is that in the next 30 years, we're going to have almost explosive increase in demand. In global energy consumption, mankind must revolutionize the world energy landscape. [Slide: chart from US DOE] Renewable energies include biomass, hydropower, geothermal, wind, solar, and other – all of those come up to about 6 percent of total energy production here in the US. On the fossil side, nonrenewable energies consist of about 94 percent.

We have to set in priority our requirements, so how do we evaluate and compare our energy options for major R&D activities for the future of mankind? That seems to be a major challenge for us. We need to define major criteria. A lot of people argue about what is the best source of energy? And there can be as many answers as many different interest groups on earth. Then, one must ask how should we even begin to look for the best solution? Scientifically speaking, when you compare and evaluate, you have to define major criteria. It has to be quantifiable. In my view, it (energy) has to be affordable for all human beings at low cost. It has to be non-depletable in terms of the livable planetary lifetime. It has to cause no harm to the environment, our ecosystem, or human lives. And it must be easily available and accessible around the globe. It has to be in usable, flexible, and scalable energy forms, and there must be low risk of potential misuse for mass destruction.

When we set key requirements, they have to be achievable. The energy options have to satisfy the needs and goals of humanity. It has to help retain and improve human values and enhancing global collaborations. It must be highly achievable through demonstrated human creativity within foreseeable future. It must help expand human presence and survival within our solar system. And it has to be consistent in elevating human culture, quality of life, and civilization.

6. Energy Options

In the comparison of key energy options, major nonrenewable energy sources, fossil fuels (oil/gas) will be depleted in another 40 to 60 years. Coal will be deleted in about 500 years. Some people estimate a thousand years, but that doesn't really matter. Before you deplete the coal, your global environment already has caused catastrophic changes. Nuclear fuels for fission reactors will deplete in about 50 years as well. All fossil fuels are harmful to Earth's biosphere, and as well all know nuclear power has major issues with waste deposit, and the risks of proliferation and misuses are high. Nuclear, after all had 40 years' chance already to resolve the world's acute energy problems, and it didn't help the world solve the problem at all! On the other hand, as an excellent concept of space solar power which brought out by Dr. Peter Glaser some 4 decades ago, have we humans given a fraction of the time or attention the SSP deserves?

Major renewable energy sources: hydro power – limited and unstable water resources; liquid biomass – competes land with food production. You have heard that in Mexico tortilla prices have gone up about 50 percent in two years. Hydrogen (fuel cell) has high risks for storage and transportation. Wind/geothermal/tidal are intermittent, unstable forms of energy, and they are very costly. Nuclear fusion is unlikely to achieve in foreseeable future, and it has a high risk for harm and misuses for destructive purposes. Something that offers tremendous energy can always be potentially misused. However, Solar energy, basically as a general case – doesn't matter if it is surface- or space-based – is achievable, has no limit, and there's no harm to human beings.

Harnessing the Sun is the next giant leap for mankind. Why the Sun? People ask that. Harnessing the Sun is like our ancestors first harnessed the wild fire: it's an inevitable and logical leapfrog in the process of human evolution. Before reaching the tipping point of the globe, it's time for humans to tame the natural forces of the Sun and harness it for the well-being and survival of our species. The best place, of course, for a nuclear fusion reactor is about 149E6 km (149 x 10^6 km) away. It's free of charge! The Sun's energy only takes 8 minutes to arrive and leaves no radioactive waste, and it's of course, terrorist proof. Our Sun puts out about 3.8E11 TWh of energy per hour. Our planet receives about 174,000 terawatt each second. Every hour, Earth's surface gets more solar power than humans use in the whole year.Why can't we humans to find a way to bypass the solar-to-fossil inefficiency, when looking at our energy solutions?! About 4.6 billion years ago, the Earth was just formed, and it was 3.5 billion years ago that there was the first sign of life. Not until 1.5 billion years ago was there multicell biology; really, life started just around 0.5 billion (or 500 million) years ago. The dinosaur lived about 150 million years ago and went extinct. Human beings have lived maybe a few hundred thousand years. You can see that it took about 3.5 billion years and rare geologic events to sequester hydrocarbons and build up hydrogen in the atmosphere. If you do a little calculation, you will find that using direct solar energy is 1,200,000,000,000 times more efficient than using oil dug out of ground. Why not go direct to the Sun for energy?

7. Global energy potentials

Here are some interesting numbers you can see. Direct solar radiation is humongous [350,000,000 terawatt hours/year]; nothing compares with it. Energy stored in the Earth in terawatt hours [10,800,000 terawatt hours total]. You can see the picture. I would like to call for embarking on humanity's third giant leap, which is moving from a combustion economy to a solar/electric world economy. With a combustion economy, maybe in the first hundred years, quality of life went up, but now it goes down drastically. If you have an agrarian economy, quality of life doesn't go up either. Only in a Solar-electric economy do you have energy production going up and you have quality of life going up as well.

Key challenges in harvesting the Sun are technology R&D challenges, basically. Solar/electric, solar/thermal, solar/chemical, battery storage technologies – those are where I see the critical needs for significant increase in conversion and storage efficiencies, and we have to reduce cost. There is also the issue of cost and investment challenges. You have to compete with other energy sources, because we are human beings and economics drives technologies, like it or not, as we said. We have no choice; basically, it's human nature. So, the political and social challenges are even bigger. We have to overcome the nuclear/fossil establishment lobbyists and rectify public perception and rediscover the Sun. Space solar power had a chance in the middle 1970s. NASA and DOE spent a lot of time on a study, but it was the nuclear lobbyists that killed it back then. The Space Solar Power never had a chance. Nuclear had over 40-years of chance to demonstrate that it's a viable option.

Why solar energy from space? The challenge of terrestrial solar power is that we have less than one percent of the world's energy coming from solar power due to PV costs and inefficiency. To power the whole US electricity needs would require a field of solar panels the size of the state of Vermont. And to satisfy world consumption requires about one percent of the land that is used for agriculture worldwide unless there are breakthroughs made in conversion efficiency. So, there is roughly about 7 to 20 times less energy per square meter on Earth than in space, depending on the geological locations.

Is SSP [space solar power] a viable energy option? It satisfies every key major criteria of the viable energy option except the cost. We all know that cost is a key issue. Space solar power is an achievable human technology/engineering endeavor, based on many demonstrated heritages of human ingenuity. We can go to the Moon and came back safely; we can achieve splitting atoms; we can most certainly overcome the problem of the solar-electric conversion, and making it affordable to everyone on earth!. Key SSP component technologies will also enable human economic expansion and settlement into space, which is extremely important. It provides an ideal platform for human collaborations that will help reduce the global economic imbalances. It is also a major steppingstone for humanity's third giant leap that is likely to transpire, elevating our species.

Key challenges of SSP include that since the 1970s, interest in SSP faded almost as fast as the lines at the gas pumps receded. This signifies a lack of vision and leadership in policy-makers. The political system has been a key obstacle for SSP to be developed by mankind due to fossil and nuclear energy establishments and the existing economic infrastructures. We already got ourselves into the fossil-based combustion civilization; yes it's not easy to change it. But, we must start to change it now for the future of mankind. The key changes are much less technical or economic in nature, than social and political in reality. It's truly a policy issue. It's not quite a technology or economic issue. We must remove the perceived high risk of WPT (wireless power transmission) on human health and the ecosystem via extensive scientific investigations. We have to do that. There was recently a demonstration in Paris because people were worried about the cell phone and its impact on human health. That's going to be a big issue if we fail to address it early. Can mankind achieve the third giant leap into the solar-electric civilization? Humans have been capable of profound achievements as huge as the Manhattan and Apollo projects. We can certainly succeed in SSP and achieve our next giant leap forward in transforming humanity from a combustion civilization to the forever-sustained solar-electric civilization. We can make it happen – but not if we fail to educate and mobilize the younger generation, the politicians and decision-makers around the globe.

People always argue: "It is too costly; we cannot do it." The real challenge for mankind for solar power satellites is really a "Manhattan Project for peace." For a space race for wining the cold war, it's easy and we can achieve it, but to do something gigantic for peace, it's not easy. It's not in our human nature. But Dr. Robert Goddard, the father of modern rockery liked to say: "It is difficult to say what is impossible, for the dream of yesterday is the hope of today and the reality of tomorrow." I would like to think that, as intelligent creatures rooted in our cosmic origin, humanity was meant to spread its presence all over the universe by milking the energy of the stars. This is my high-level yet realistic road map for achieving the dreams of global energy abundance and sustainability: Advocate massive global-scale use of terrestrial solar energy – we need to starting from grassroots level, large scale use of Earth-based solar energy. By doing that, extensive R&D activities will happen for breakthroughs in PV and WPT technology (photovoltaic & wireless power transmission). By doing that, you're going to bring about extensive R&Ds for breakthroughs in nanotechnology-based high efficiency & low cost PV solar cells and electric storage technologies. By doing that, you're going to bring about extensive R&Ds in low-cost RLVs (reusable and low cost launch vehicles) or robotic technology. And by doing all of these three major things, you're going to significantly reduce the payload for SPS (solar power satellites), thus for affordable Space Solar Power.

When we talk about "too expensive to launch for SPS," why not thinking about how to reducing the weight, or payload? If we don't need that much to send to space; we can significantly reduce space transportation costs. Overall, we're going to need strong political and government support. We need to apply a smart commercial model like ComSat – how we succeeded in mobile phone communication and in TV broadcasting. By doing that, we can trigger a large, affordable SSP project. You never know, if the PV efficiency and energy storage technologies were to become so advanced and that the cost of terrestrial solar power has declined dramatically, then there may be one day that we no longer need to launch large SPS installations into space except of course, for space-based economic development and for human exploration into the cosmos! Lastly, we have 40 years, maybe 50 years, of oil left. We have 5,500,000,000 years of sunshine left. Choose wisely.

8. The State-of the-Art in Technology

The major issues that need to be addressed in microwave power beaming system applications are cost; safety, and power transfer efficiency, which include frequency allocations, transmission distances, and size of the receiver and emitter. For terrestrial power beaming the issue of cost is the hardest to assess because of the multitude of variables it includes. Like in any new developing industry the initial cost is "High" because of the technology development cost, the infrastructure development cost, and the market acceptability development cost. Here a phased engineering and development approach is essential, starting with present state of the art in technology and engineering producing markets and profit at each phase to multiple users to aid garnering revenues and feed the next phase of market development. Also, if power-beaming systems could be engineered to use standard parts then economies of scale during production could have a beneficial impact. Smart market strategies are needed such as open architectures and dual mode dc-RF converters for bi-directional power flow utilities and economies of scale in energy transport. The issue of safety can be addressed by asking the question "Can a microwave beam system be engineered that allays the public perception of "Fear of radiation harmful effects" knowing that an average household uses microwave routinely "to cook" in their kitchen. Experimental data associated with medical diagnosis, alert sensors, openness, transparency, and education is essentials to responding to this issue satisfactorily. Also, additional radar surveillance, and side lobe detecting systems could be installed and be continuously remotely monitored to insure that no harmful radiation interferes with avionics, electronics, or cell phone systems. Within the scientific community, many issues come to the surface, as the main issue of concern is the impact of a specific frequency's interference with the frequencies already assigned to the various civilian, governmental, technical and scientific communities. The potential is real for causing destructive interference out of band if proper engineering is not implemented through filtering harmonics and the prevention of potential intermodulation and re-radiation. International collaboration with setting priorities for spectrum usage should provide a part of the solution. On the wireless power transmission system-engineering front, key issues have handicapped progress toward practical demonstration. These include beam polarization, frequency vs. size for the transmitting and receiving apertures, humidity in the air, aperture tracking vs. electronic beam steering, solid state vs. tube amplifiers, beam coupling efficiency, aperture power density, taper vs. side lobe levels, rectenna array design, filled or unfilled, separation between emitter and receiver, etc.

There are 2 tracks where microwave power systems can evolve; non-radiating, wherein the RF field are confined inside metallic waveguides and radiative wherein the fields propagate through free space. In the first approach there would be only issues of system architecture, supportive infrastructure needed, and cost (an example would be the high power high frequency RF used for plasma heating in fusion research). However, this approach eliminates the most attractive feature of this technology, which is the Wireless Power Transmission (WPT). The most useful applications require radiation within and to and from the atmosphere and space. Existing low power systems, which are the most widely used applications are 1- 2 Vdc output voltage over a transmission distance of few meters for which power density less than 0.5 mW/cm2 is required (*e.g.,* Radio frequency identification RFID), Improvised Explosive Devices (IED), Counter Radio Controlled Improvised Explosive Device Electronic Warfare (CREW), and medical diagnostics. Existing medium to high power microwave applications are for communicating with spacecraft, space objects, aircraft for radar and telecommunications purposes, mob control, and mine detection. Transferring significant levels of electric power through free space is the prime intent of this paper.

9. The Spectrum Issue

The losses in microwave power beaming propagation through the atmosphere are related to the wavelength of the radiation compared to the size of scattering particulates in the atmosphere such as raindrops, cloud drops, dust particles, ice crystals, hail, and snow flakes. The larger the wavelength compared to the scattering particulates, the lower the power losses. The penalty with that approach is that in order to focus a tight beam, the long wavelengths will require a very large diameter aperture. Tight beams can be obtained with smaller diameter apertures if short wavelengths are employed, however, the atmosphere has severe absorption lines at the high frequencies. There are windows of acceptable propagation losses in the high frequency regions of the spectrum, allowing trade between large-diameter apertures all weather performance and acceptable propagation loss small-diameter apertures. But, the fact remains that the RF spectrum is already occupied by many diverse users with many different science and market applications covering radio locations, broadcasting, inter-satellite, astronomy, etc. without any allocations for beamed power services. The other issue, which needs to be addressed in frequency allocations, is the out-of-band interference, the radiation of harmonics of the fundamental beamed power frequency. This problem may be solved by well-engineered low-pass and band-stop filters at the receiver arrays and by minimizing transmitter harmonic generation in order to yield high conversion efficiencies and no losses. The possibility of lower RF frequencies mixing in the nonlinear converters can be prevented by the use of half wave slot aperture coupling of the fundamental into and out of the converter. Higher than the fundamental frequencies and the subsequent re-radiation can be eliminated with narrow-band pass filters.

10. Conclusion

It has been shown that one may construct the very large transmit arrays needed for power beaming using a modular philosophy in which two or more layers of control and synchronizing arrays can be used to steer the beam of a hierarchy of sub-arrays In addition, for moderate power transmission requirements (much less than the gigawatts proposed for space to earth systems and for ranges up to 10s of kilometers) we have demonstrated that beam combining techniques can be used to design antennas capable of focusing power beams within the Fresnel region to increase coupling efficiency. Of course such low aperture power densities also facilitate signal-conditioning techniques such as frequency filtering and element weighting for side lobe control. High efficiency power transfer requires the use of a receive aperture that is as large as is practical for the particular application. However, acceptance of less than 100% transfer efficiency permits relaxation of the aperture size and proximity requirements. To fully exploit power beaming for the lunar and space environment, higher transmission frequency components must be developed to reduce system size and mass. This includes power amplifiers (or compact tubes) as well as conversion devices (rectennas or cyclotron wave converters). The technology is within reach and the urgency for action is never greater.

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